REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE Technical Papers	3. DATES COVERED *(From - To)*
4. TITLE AND SUBTITLE		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Air Force Research Laboratory (AFMC) AFRL/PRS 5 Pollux Drive Edwards AFB CA 93524-7048		8. PERFORMING ORGANIZATION REPORT
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Air Force Research Laboratory (AFMC) AFRL/PRS 5 Pollux Drive Edwards AFB CA 93524-7048		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

20020917 037

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Leilani Richardson
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified	A		19b. TELEPHONE NUMBER *(include area code)* (661) 275-5015

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. 239.18

9 items enclosed

* Paper Rec'd. After 30-day Deadline = 20 days until Deadline

MEMORANDUM FOR PRS (In-House Publication)

FILE

FROM: PROI (STINFO)

05 August 2002

SUBJECT: Authorization for Release of Technical Information, Control Number: **AFRL-PR-ED-TP-2002-200**
Ed Coy and Doug Talley (PRSA), "Multiphase Detonations for Pulse Detonation Rocket Engines"

56174

AFOSR Contractors Meeting
(Colorado Springs, CO, 22 August 2002) **(Deadline: 22 August 2002)**

(Statement A)

Multiphase Detonations for Pulse Detonation Rocket Engines

Douglas G. Talley, Edward B. Coy, Jonathan M. Watts, AFRL/PRSA
10 East Saturn Blvd.
Edwards AFB, CA 93524-7660

douglas.talley@edwards.af.mil	661 275 6174
edward.coy@edwards.af.mil	661 275 5219
jonathan.watts@edwards.af.mil	661 275 5237

Task 93P1002

Abstract

Recent efforts in PDRE research at AFRL-West have focused on basic studies of the detonation or constant-volume combustion of multiphase mixtures. A collaborative effort is under way for developing models appropriate for PDRE application studies. This effort includes a new facility for the collection of data on liquid oxygen/gaseous fuel detonations. The facility has been designed to provide accurate and flexible control over the initial conditions of the multiphase mixtures and complete characterization of detonation parameters including initiation energies, wave speeds, pressures and rates of heat transfer. Model development is being performed by Metacomp Technologies and University of Colorado. A second experimental effort is examining the feasibility of a monopropellant-fueled pulse combustor. Analytical and numerical studies have shown the performance benefits of this approach and a preliminary system study has shown that there are significant benefits in satellite applications. An experimental demonstration of the concept is under way.

Introduction

Pulse Detonation Engines will operate in a multiphase regime that has not previously been characterized. A great deal is known about condensed-phase and purely gaseous detonations, and some work has been done in dilute sprays, however, there has not previously been a technological application that utilized detonations in the density ranges that are relevant to rocket propulsion. One of the goals of this program is to determine the conditions under which liquid oxygen sprays can be successfully detonated including the effects of droplet size, vapor fraction, turbulence level on detonation wave speed, pressure history and ignition sensitivity. It will provide data for developing models of droplet shattering and vaporization as well as the effects of heat transfer and wall friction in the extended reaction zones that exist for multi-phase detonations. This data is needed for model development and code verification for performing PDRE feasibility studies.

A second goal of this program is to explore constant-volume combustion as an alternative to pulsed-detonation. Similar advantages to those already identified for pulse detonation engines could be achieved in a device operating with a constant or near-constant volume combustion cycle. In fact, pulse detonation devices approach the constant-volume limit when there is sufficient time for transient waves within the combustion chamber to decay before a significant fraction of the mass has exited the nozzle. This limit could be achieved in practice by placing a hot-gas valve in the exit of the combustion chamber, or simply by building a chamber with a large volume relative to the nozzle throat area, such that the blowdown time of the chamber is much longer than the reaction time of the propellants. We are exploring this alternative from several angles, including basic thermodynamic theory, lumped-parameter system modeling, and an experimental demonstration.

Experimental Approach:

LOX/Hydrogen Detonations: Facility and test article design and fabrication are complete. Preliminary operations using inert simulants are being performed as this abstract is being written and initial detonation tests are imminent. Figure 1 shows the detonation tube with the associated valving and instrumentation. The tube has an inner diameter of 1", a length of 24" and a design pressure of 10,000 psi. The initial quality of the injected LOX is controlled through the Joule-Thomson expansion process at the injector orifice. The hydrogen is chilled prior to injection to suppress vaporization of the liquid oxygen and to be simulative of the injection conditions typical of engines regeneratively-cooled with hydrogen. The initial pressure and density within the tube is controlled with an adjustable exit orifice. The ignition system is based on a conventional automotive system with an additional final capacitive discharge stage that allows the system to build to a higher voltage allowing briefer and higher power spark discharges. This system also allows spark energy to be varied to find the minimum energy for detonation initiation.

The detonation tube and propellant systems are pre-chilled with liquid nitrogen. The tube is instrumented with two sets of transducers: cryogenic temperature sensors and low-pressure transducers for characterizing the initial mixture conditions, and piezoelectric and flame ionization detectors for characterizing the detonation.

The experiment is sited in a remote test area and is operated from a control console in a blockhouse.

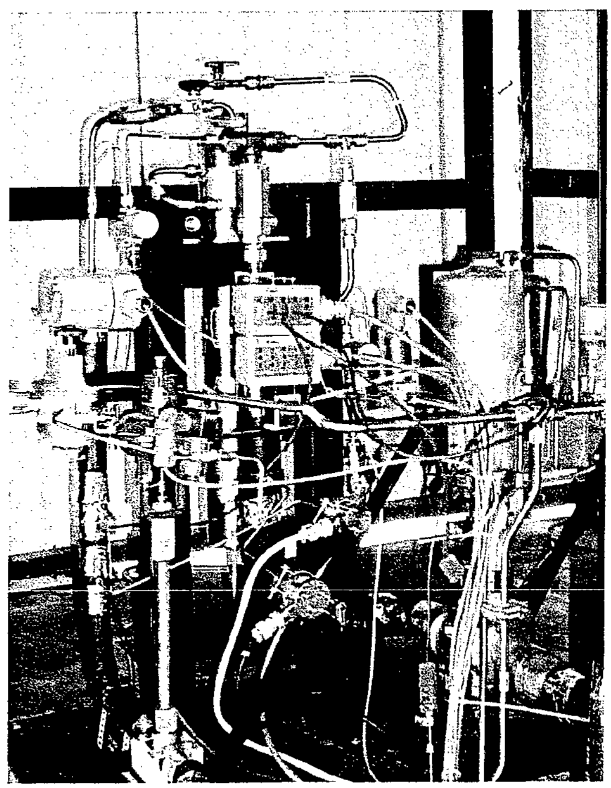


Figure 1 Multiphase detonation test article

Constant-Volume/Pulse Combustor Demonstration: Test article has been designed and fabricated and is shown in figure 2. Test facility buildup is pending. The device was designed using an in-house lumped parameter code that models the transient processes of liquid injection, droplet burning and chamber blowdown. The nominal thrust of the device is 10 lbf and it is designed to operate at frequencies up to 100 Hz. The fuel is a liquid monopropellant. The characteristic length of the combustion chamber is adjustable and can range from 30 to 300 inches. The injector is based on a high-speed solenoid valve coupled to a poppet. Check out tests using high-speed video of the injector poppet showed that bounce was occurring. This problem has been eliminated by raising the injection pressure. Ignition can be by glow plug or a hydrogen/oxygen torch.

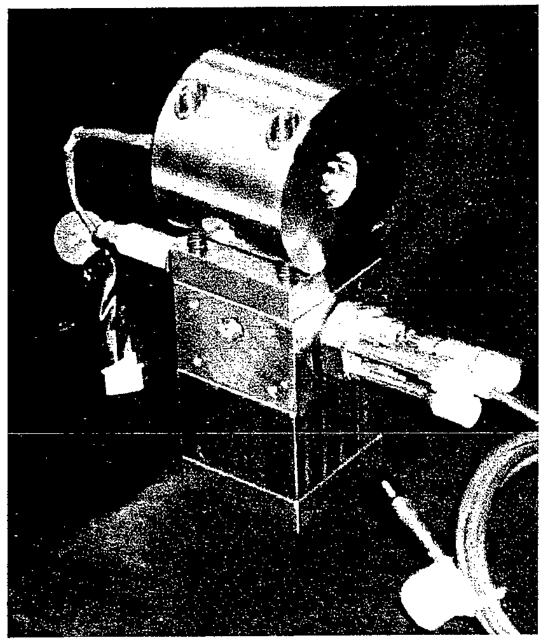


Figure 2 Monopropellant pulse combustor

Analytical and Computational Studies:
Since the last reporting period we have performed and published analytical and computational studies of PDRE feasibility[1]. The constant volume limit of pulsed propulsion was explored, where the combustion chamber is approximated as being time varying but spatially uniform and the nozzle flow is approximated as one dimensional but quasi-steady. This basic model was explored theoretically, by assuming instantaneous heat release, and computationally using a finite heat release model. These models have also been used in the design of test articles as well as in the system study described below.

Accomplishments/New Findings: A preliminary system study of satellite applications for PDRE was completed. We considered replacing a MMH/NTO apogee engine on a 10,000 lb class satellite with a PDRE. Two scenarios were considered and the results of the comparison are given as PE-1 and -2 in the table below. PE-1 used the same feed system and injection pressure as the baseline engine, and also maintained the same engine envelope and average thrust. The PDRE produces a higher Isp than the conventional engine because it operates at a higher average chamber pressure, and therefore can achieve the same thrust level with a smaller throat. Since the nozzle exit area is kept the same, the PDRE operates with a larger expansion ratio that translates into a 6-second improvement in Isp. In the second scenario, the engine thrust, average chamber pressure and engine envelope were held constant, but the injection pressure was reduced in order to realize weight savings in the feed system. Specifically the injection pressure was reduced from 100 to 37 psia producing a reduction in tank weight from 49 to 35 lbm for a titanium, spherical tank.

Either of the above improvements can return significant improvements in satellite life. One second of Isp is worth 50 days of extra life. Manufacturers have demonstrated a willingness to pay extra recurring cost of \$25K per second of Isp improvement plus one time cost of qualification (> \$1M).

Relevance/Transitions:

Relevance to AF Mission: The Air Force is interested in improving the performance of space propulsion systems to increase payload capability and extend satellite lifetimes.

PDREs may offer advantages over conventional constant-pressure systems in cost and performance and the production of rapid and variable impulse bits. Efforts to date have focused on building demonstration devices using gaseous propellants. However, there is a consensus within AFRL that practical systems will need to operate on condensed fuels. This program will provide data and an improved understanding of multiphase detonations of typical rocket propellants as well as fuels that may be particularly suited to PDRE applications.

Where Knowledge is Used: Results of this study will be used by designers of PDRE's as well as analysts seeking to develop accurate performance prediction methodologies for these engines. These activities will require quantitative data over a wide range of conditions as well as physically motivated qualitative understandings of multiphase detonation phenomena.

	R-4D-11	PE-1	PE-2
Thrust (lbf)	100	100	100
$P_{C.\ MINIMUM}$ (psia)	100	100	37
$P_{C.\ MAXIMUM}$ (psia)	100	440	160
Mass Flow (lbm/s)	0.316	0.310	.316
A_{EXIT}/A_{THROAT}	164	375	164
D_{throat} (inch)	0.752	0.497	.752
D_{exit} (inch)	9.63	9.63	9.63
$D_{chamber}$ (inch)	2.0	1.30	2.0
L_{motor} (inch)	23.8	22.5	23.8
I_{SP}	316	322	316
Motor Wt. (lbm)	8.8	11.7	8.8
Tank Wt. (lbm)	49	49	35

Publications/References:

[1] Talley, D.G., Coy, E.B., "Constant Volume Limit of Pulsed Propulsion for Constant γ Ideal Gas", J. Propulsion and Power, Vol. 18, No. 2, March-April 2002

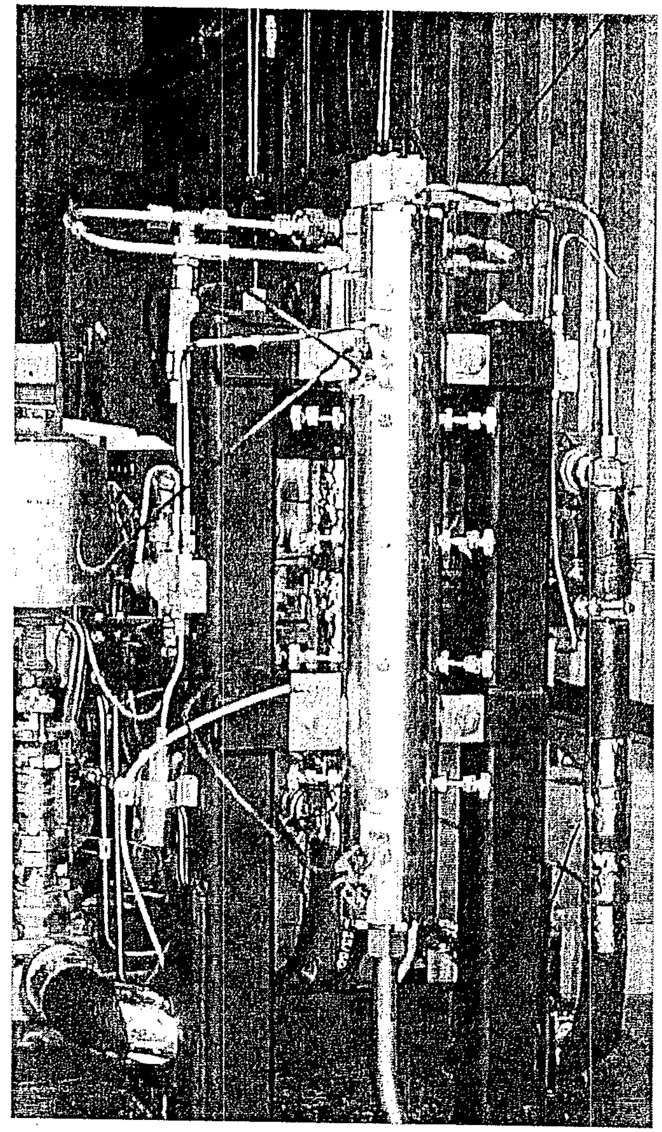
Detonations of Multiphase Mixtures

Objectives

- Determine effects of droplet size, liquid loading density, turbulence level on initiation energy, wave speed, and P3 pressure
- Provide data for developing models of LOX spray detonations for use in system studies of PDREs

Approach

- Cryogenic LOX/Hydrogen/HC to begin with
- Chamber designed to withstand 10,000 psi.
- Accurate and flexible control of initial conditions
- Controlled degree of vaporization through isenthalpic expansion of LOX
- Hydrogen chiller to simulate regeneratively cooled engine conditions



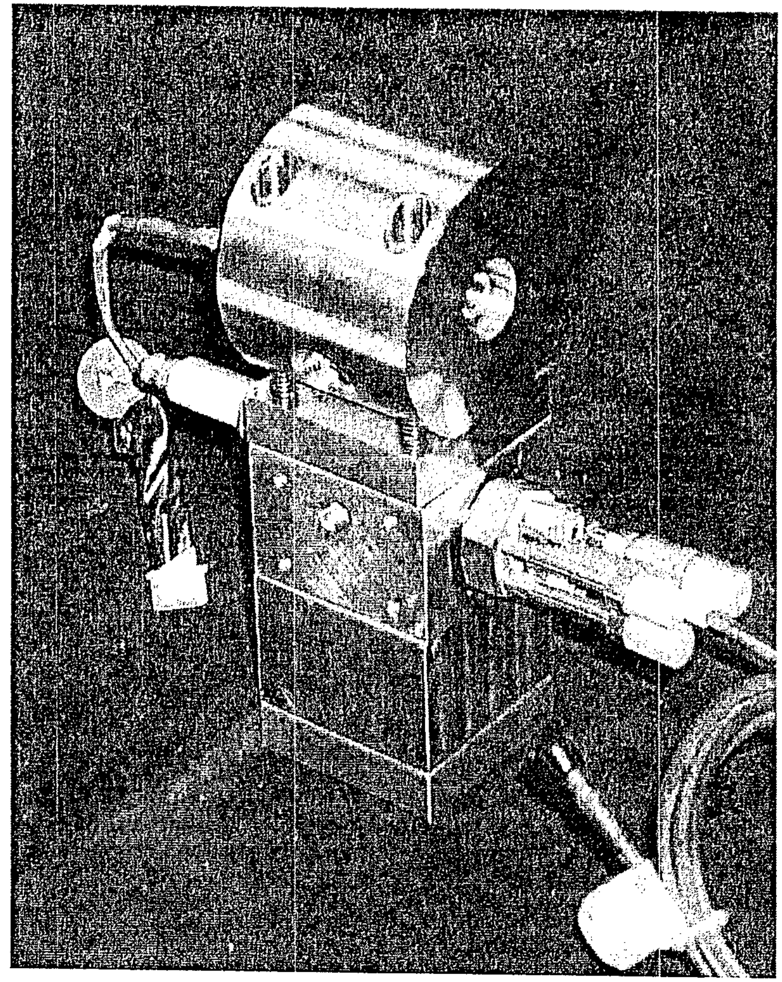
Pulse Combustor

Objectives

- Demonstration of constant-volume limit of pulsed combustion
- Achieve average chamber pressure greater than average injection pressure
- Eliminate need for ignition system and hazards of liquid detonations

Approach

- Variable L*
- High speed solenoid valve and poppet valve
- Glow plug ignition or hydrogen-oxygen torch
- Helium-bleed, water-cooled dynamic pressure
- Stand-alone, portable experiment
- Designed using in-house CV combustion code
- Liquid monopropellant or liquid/gas bipropellant



Status

Detonations of Multiphase Mixtures

- Facility is complete and tested with inerts
- Combined System Test scheduled for 5 August 02
- High speed DAQ checkout with shock driver – 9 August 02
- LOX/GH2 detonations 12 August 02
- Collaborating on modeling effort with Palaniswamy (Metacomp) and Kassoy (U. Colorado).

Pulsed Combustor (Constant-Volume Cycle)

- Results of analytical model have been published
- Test article is complete
- Poppet valve operation tested with water and visualized with high speed camera
- Safety and Bio-environmental approvals in process
- First firings planned for October 02

Potential Future Payoff

- Two scenarios for replacing a 100 lbf NTO/MMH Apogee engine with a PDRE. Mission is LEO-GEO Transfer, 4000 lbm initial weight, $\Delta V = 4$ Km/s
  - PE-1: Injection pressure same as R-4D-11 but higher average Pc gains 6s Isp, saving propellants for station keeping worth $$ tens of millions in increased time on station.
  - PE-2: Average chamber pressure same as R-4D-11 but reduced injection pressure saves weight worth 50 days of station keeping.

	R-4D-11	PE-1	PE-2
Thrust (lbf)	100	100	100
$P_{C, MINIMUM}$ (psia)	100	100	37
$P_{C, MAXIMUM}$ (psia)	100	440	160
(lbm/s)	0.316	0.310	.316
A_{EXIT}/A_{THROAT}	164	375	164
D_{throat} (inch)	0.752	0.497	.752
D_{exit} (inch)	9.63	9.63	9.63
$D_{chamber}$ (inch)	2.0	1.30	2.0
L_{motor} (inch)	23.8	22.5	23.8
I_{SP}	316	322	316
Motor Wt. (lbm)	8.8	11.7	8.8
Tank Wt. (lbm)	49	49	35